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Description

Hybrid Vehicle, Control Method of Hybrid Vehicle, and Power Output Apparatus

5 **Technical Field**

The present invention relates to a hybrid vehicle, a control method of the hybrid vehicle, and a power output apparatus.

10 **Background Art**

One proposed hybrid vehicle has an engine, a planetary gear unit including a carrier and a ring gear respectively linked to a crankshaft of the engine and to a drive shaft, a first motor connected to a sun gear of the planetary gear unit, 15 a second motor connected to the drive shaft, and a battery capable of transmitting electric power to and from the first motor and the second motor (see, for example, Japanese Patent Laid-Open Gazette No. 11-93727). In this proposed hybrid vehicle, the first motor is driven and controlled to regulate 20 the rotation speed of the engine.

Disclosure of the Invention

In the hybrid vehicle equipped with the engine and the driving motor, the general control procedure varies the 25 rotation speed of the engine and intermittently activates and inactivates the engine with a variation in required engine power,

in order to enhance the energy efficiency. In response to the driver's deceleration demand, the required engine power basically decreases to 0 or to a braking power level (friction work) and accordingly lowers the engine rotation speed. The

5   driver may give a high acceleration demand immediately after the deceleration demand. The driving motor is activated with electric power supply from the battery to compensate for an insufficient power due to a poor response of the engine. A high-capacity battery sufficiently supplies required electric

10 power to supplement the power insufficiency, but naturally has large dimensions and mass to be unsuitable for the equipment of the hybrid vehicle. A low-capacity battery, however, can not sufficiently supply required electric power to supplement the power insufficiency. A large power insufficiency

15 increases the required electric power to be discharged from the battery. Repeated charges and discharges of the battery with relatively large electric powers even within an allowable range of input and output limits undesirably cause premature deterioration of the battery.

20   The hybrid vehicle, the control method of the hybrid vehicle, and the power output apparatus of the invention thus aim to enhance a response to a demand for varying power output from an internal combustion engine. The hybrid vehicle, the control method of the hybrid vehicle, and the power output

25 apparatus of the invention also aim to reduce the loading of an accumulator unit, such as a secondary battery. The hybrid

vehicle, the control method of the hybrid vehicle, and the power output apparatus of the invention further aim to enhance the energy efficiency of the hybrid vehicle or the power output apparatus.

5   At least part of the above and the other related objects are attained by the hybrid vehicle, the control method of the hybrid vehicle, and the power output apparatus having the configurations and arrangements discussed below.

        The present invention is directed to a hybrid vehicle
10   including: an internal combustion engine; an electric power-mechanical power input output mechanism that is connected to an output shaft of the internal combustion engine and to a drive shaft linked with one axle of the hybrid vehicle and inputs and outputs power from and to the output shaft and the drive
15   shaft through input and output of electric power and mechanical power; a motor that inputs and outputs power from and to either of the one axle and the other axle, which is different from the one axle; an accumulator unit that transmits electric power to and from the electric power-mechanical power input output
20   mechanism and the motor; a drive power demand setting module that sets a drive power demand required for a drive of the hybrid vehicle; a vehicle speed measurement module that measures vehicle speed of the hybrid vehicle; a lower rotation speed limit setting module that sets a lower rotation speed limit,
25   which represents a minimum allowable rotation speed of the internal combustion engine, corresponding to the measured

vehicle speed; and a control module that controls the internal

combustion engine, the electric power-mechanical power input

output mechanism, and the motor to drive the internal combustion

engine at a rotation speed of not lower than the set lower

5   rotation speed limit and to drive the hybrid vehicle with a power

corresponding to the set drive power demand.

    The hybrid vehicle of the invention sets the lower

rotation speed limit, which is the minimum allowable rotation

speed of the internal combustion engine, corresponding to the

10   measured vehicle speed. The internal combustion engine, the

electric power-mechanical power input output mechanism, and the

motor are controlled to drive the internal combustion engine

at a rotation speed of not lower than the set lower rotation

speed limit and to drive the hybrid vehicle with a power

15   corresponding to the set drive power demand. The internal

combustion engine may increase the output power by increasing

only the rotation speed with a fixed output torque or by

increasing only the output torque with a fixed rotation speed.

The output torque increase attained by varying the intake air

20   flow and the amount of fuel injection requires a less time than

the rotation speed increase. The output power increase with

the output torque variation can thus be attained within a

shorter time period than the output power increase with the

rotation speed variation. The internal combustion engine

25   driven at the rotation speed of not lower than the lower rotation

speed limit, which depends upon the measured vehicle speed, has

a quicker response to a demand for a power increase to be output from the internal combustion engine. This arrangement desirably decreases the output power of the motor, which is activated to compensate for an insufficiency of the power

5   required for driving the hybrid vehicle due to a delayed response of the internal combustion engine, thus effectively reducing the loading of the accumulator unit.

In one preferable embodiment of the invention, the hybrid vehicle further includes a rotation speed demand setting module

10   that sets a rotation speed demand, at which the internal combustion engine is to be driven, corresponding to the set drive power demand. The control module controls the internal combustion engine, the electric power-mechanical power input output mechanism, and the motor to drive the internal combustion

15   engine at a higher rotation speed between the set lower rotation speed limit and the set rotation speed demand. The internal combustion engine is thus driven at the rotation speed determined by taking into account both the rotation speed demand, which depends upon the drive power demand, and the lower

20   rotation speed limit, which depends upon the vehicle speed. Namely the internal combustion engine is driven at an adequate drive point. The rotation speed demand setting module may set the rotation speed demand to a specific rotation speed of the internal combustion engine that ensures efficient output of the

25   power corresponding to the set drive power demand from the internal combustion engine. This arrangement maintains the

high response of the internal combustion engine, while enhancing the energy efficiency of the hybrid vehicle.

In the hybrid vehicle of the invention, it is preferable that the lower rotation speed limit setting module sets the lower rotation speed limit to a rotation speed of not lower than a specific rotation speed of the internal combustion engine at a specific drive point that ensures efficient output of a required power from the internal combustion engine for a constant-speed drive of the hybrid vehicle on substantially flat road surface at the measured vehicle speed. Even in the case of a small current power demand to be output from the internal combustion engine, this arrangement enables the internal combustion engine to promptly output a power required for a constant-speed drive of the hybrid vehicle or a greater power, in response to a subsequent demand for an output power variation.

In the hybrid vehicle of the invention, it is also preferable that the control module controls the internal combustion engine, the electric power-mechanical power input output mechanism, and the motor to stop fuel injection to the internal combustion engine, when the set drive power demand is equivalent to a predetermined braking power for braking the hybrid vehicle. This arrangement improves the fuel consumption and enhances the total energy efficiency of the hybrid vehicle.

In the hybrid vehicle of the invention, it is preferable

that the electric power-mechanical power input output mechanism
includes a three shaft-type power input output module that is
linked to three shafts, that is, the output shaft of the internal
combustion engine, the drive shaft, and a rotating shaft, and

5　automatically determines power input from and output to a
residual one shaft based on powers input from and output to any
two shafts among the three shafts; and a generator that inputs
and outputs power from and to the rotating shaft. Further, it
is preferable that the electric power-mechanical power input

10　output mechanism includes a pair-rotor motor that has a first
rotor connected to the output shaft of the internal combustion
engine and a second rotor connected to the drive shaft and is
driven through relative rotation of the first rotor to the
second rotor.

15　　　The present invention is directed to a power output
apparatus that outputs power to a drive shaft and includes: an
internal combustion engine; an electric power-mechanical power
input output mechanism that is connected to an output shaft of
the internal combustion engine and to the drive shaft and inputs

20　and outputs power from and to the output shaft and the drive
shaft through input and output of electric power and mechanical
power; a motor that inputs and outputs power from and to the
drive shaft; an accumulator unit that transmits electric power
to and from the electric power-mechanical power input output

25　mechanism and the motor; a power demand setting module that sets
a power demand required for the drive shaft; a rotation speed

measurement module that measures rotation speed of the drive

shaft; a lower rotation speed limit setting module that sets

a lower rotation speed limit, which represents a minimum

allowable rotation speed of the internal combustion engine,

5   corresponding to the measured rotation speed; and a control

module that controls the internal combustion engine, the

electric power-mechanical power input output mechanism, and the

motor to drive the internal combustion engine at a rotation

speed of not lower than the set lower rotation speed limit and

10   to output a power corresponding to the set power demand to the

drive shaft.

       The power output apparatus of the invention sets the lower

rotation speed limit, which is the minimum allowable rotation

speed of the internal combustion engine, corresponding to the

15   measured rotation speed of the drive shaft. The internal

combustion engine, the electric power-mechanical power input

output mechanism, and the motor are controlled to drive the

internal combustion engine at a rotation speed of not lower than

the set lower rotation speed limit and to output a power

20   corresponding to the set power demand to the drive shaft. As

described above, the output power increase with the output

torque variation can be attained within a shorter time period

than the output power increase with the rotation speed variation.

The internal combustion engine driven at the rotation speed of

25   not lower than the lower rotation speed limit, which depends

upon the measured rotation speed of the drive shaft, has a

quicker response to a demand for a power increase to be output from the internal combustion engine. This arrangement desirably decreases the output power of the motor, which is activated to compensate for an insufficiency of the power

5   required for the drive shaft due to a delayed response of the internal combustion engine, thus effectively reducing the loading of the accumulator unit. The power output apparatus of the invention may be mounted on a vehicle, which has one axle linked with the drive shaft. The internal combustion engine

10   is then driven at a rotation speed of not lower than the lower rotation speed limit, which depends upon the rotation speed of the axle. The arrangement of setting the lower rotation speed limit corresponding to the vehicle speed in place of the rotation speed of the axle is within the scope of the

15   characteristics of the hybrid vehicle of the invention described above. Namely the various embodiments and arrangements of the hybrid vehicle of the invention described above are applicable to the power output apparatus with replacement of the vehicle speed by the rotation speed of the

20   drive shaft.

The present invention is directed to a control method of a hybrid vehicle including : an internal combustion engine; an electric power-mechanical power input output mechanism that is connected to an output shaft of the internal combustion engine

25   and to a drive shaft linked with one axle of the hybrid vehicle and inputs and outputs power from and to the output shaft and

the drive shaft through input and output of electric power and

mechanical power; a motor that inputs and outputs power from

and to either of the one axle and the other axle, which is

different from the one axle; and an accumulator unit that

5   transmits electric power to and from the electric

power-mechanical power input output mechanism and the motor,

and the control method includes the steps of: (a) setting a drive

power demand required for a drive of the hybrid vehicle; (b)

setting a lower rotation speed limit, which represents a minimum

10   allowable rotation speed of the internal combustion engine,

corresponding to a measured vehicle speed; and (c) controlling

the internal combustion engine, the electric power-mechanical

power input output mechanism, and the motor to drive the

internal combustion engine at a rotation speed of not lower than

15   the set lower rotation speed limit and to drive the hybrid

vehicle with a power corresponding to the set drive power

demand.

       The control method of the hybrid vehicle of the invention

sets the lower rotation speed limit, which is the minimum

20   allowable rotation speed of the internal combustion engine,

corresponding to the measured vehicle speed. The internal

combustion engine, the electric power-mechanical power input

output mechanism, and the motor are controlled to drive the

internal combustion engine at a rotation speed of not lower than

25   the set lower rotation speed limit and to drive the hybrid

vehicle with a power corresponding to the set drive power demand.

This control procedure ensures a quick response of the internal combustion engine to a demand for a power increase to be output from the internal combustion engine. This arrangement desirably decreases the output power of the motor, which is

5   activated to compensate for an insufficiency of the power required for driving the hybrid vehicle due to a delayed response of the internal combustion engine, thus effectively reducing the loading of the accumulator unit.

10   **Brief Description of the Drawings**

Fig. 1 schematically illustrates the configuration of a hybrid vehicle in one embodiment of the invention;

Fig. 2 is a flowchart showing a drive control routine executed by a hybrid electronic control unit included in the

15   hybrid vehicle of Fig. 1;

Fig. 3 shows one example of a torque demand setting map;

Fig. 4 shows one example of an engine speed demand setting map;

Fig. 5 shows an operation line of an engine with a constant

20   curve of engine power demand Pe*;

Fig. 6 shows one example of a lower engine speed setting map;

Fig. 7 is an alignment chart showing torque-rotation speed dynamics of respective rotation elements of a power

25   distribution integration mechanism included in the hybrid vehicle of Fig. 1;

Fig. 8 schematically illustrates the configuration of another hybrid vehicle in one modified example; and

Fig. 9 schematically illustrates the configuration of still another hybrid vehicle in another modified example.

Best Modes of Carrying Out the Invention

One mode of carrying out the invention is discussed below as a preferred embodiment. Fig. 1 schematically illustrates the construction of a hybrid vehicle 20 with a power output apparatus mounted thereon in one embodiment of the invention. As illustrated, the hybrid vehicle 20 of the embodiment includes an engine 22, a three shaft-type power distribution integration mechanism 30 that is linked with a crankshaft 26 functioning as an output shaft of the engine 22 via a damper 28, a motor MG1 that is linked with the power distribution integration mechanism 30 and is capable of generating electric power, a reduction gear 35 that is attached to a ring gear shaft 32a functioning as a drive shaft connected with the power distribution integration mechanism 30, another motor MG2 that is linked with the reduction gear 35, and a hybrid electronic control unit 70 that controls the whole power output apparatus.

The engine 22 is an internal combustion engine that uses a hydrocarbon fuel, such as gasoline or light oil, to output power. An engine electronic control unit (hereafter referred to as engine ECU) 24 receives signals from diverse sensors that

detect operating conditions of the engine 22, and takes charge

of operation control of the engine 22, for example, fuel

injection control, ignition control, and intake air flow

regulation. The engine ECU 24 communicates with the hybrid

5   electronic control unit 70 to control operations of the engine

22 in response to control signals transmitted from the hybrid

electronic control unit 70 while outputting data relating to

the operating conditions of the engine 22 to the hybrid

electronic control unit 70 according to the requirements.

10   The power distribution and integration mechanism 30 has

a sun gear 31 that is an external gear, a ring gear 32 that is

an internal gear and is arranged concentrically with the sun

gear 31, multiple pinion gears 33 that engage with the sun gear

31 and with the ring gear 32, and a carrier 34 that holds the

15   multiple pinion gears 33 in such a manner as to allow free

revolution thereof and free rotation thereof on the respective

axes. Namely the power distribution and integration mechanism

30 is constructed as a planetary gear mechanism that allows for

differential motions of the sun gear 31, the ring gear 32, and

20   the carrier 34 as rotational elements. The carrier 34, the sun

gear 31, and the ring gear 32 in the power distribution and

integration mechanism 30 are respectively coupled with the

crankshaft 26 of the engine 22, the motor MG1, and the reduction

gear 35 via ring gear shaft 32a. While the motor MG1 functions

25   as a generator, the power output from the engine 22 and input

through the carrier 34 is distributed into the sun gear 31 and

the ring gear 32 according to the gear ratio. While the motor MG1 functions as a motor, on the other hand, the power output from the engine 22 and input through the carrier 34 is combined with the power output from the motor MG1 and input through the

5   sun gear 31 and the composite power is output to the ring gear 32. The power output to the ring gear 32 is thus finally transmitted to the driving wheels 63a and 63b via the gear mechanism 60, and the differential gear 62 from ring gear shaft 32a.

10   Both the motors MG1 and MG2 are known synchronous motor generators that are driven as a generator and as a motor. The motors MG1 and MG2 transmit electric power to and from a battery 50 via inverters 41 and 42. Power lines 54 that connect the inverters 41 and 42 with the battery 50 are constructed as a

15   positive electrode bus line and a negative electrode bus line shared by the inverters 41 and 42. This arrangement enables the electric power generated by one of the motors MG1 and MG2 to be consumed by the other motor. Operations of both the motors MG1 and MG2 are controlled by a motor electronic control unit

20   (hereafter referred to as motor ECU) 40. The motor ECU 40 receives diverse signals required for controlling the operations of the motors MG1 and MG2, for example, signals from rotational position detection sensors 43 and 44 that detect the rotational positions of rotors in the motors MG1 and MG2 and

25   phase currents applied to the motors MG1 and MG2 and measured by current sensors (not shown). The motor ECU 40 outputs

switching control signals to the inverters 41 and 42. The motor

ECU 40 communicates with the hybrid electronic control unit 70

to control operations of the motors MG1 and MG2 in response to

control signals transmitted from the hybrid electronic control

5   unit 70 while outputting data relating to the operating

conditions of the motors MG1 and MG2 to the hybrid electronic

control unit 70 according to the requirements.

The battery 50 is under control of a battery electronic

control unit (hereafter referred to as battery ECU) 52. The

10   battery ECU 52 receives diverse signals required for control

of the battery 50, for example, an inter-terminal voltage

measured by a voltage sensor (not shown) disposed between

terminals of the battery 50, a charge-discharge current

measured by a current sensor (not shown) attached to the power

15   line 54 connected with the output terminal of the battery 50,

and a battery temperature measured by a temperature sensor (not

shown) attached to the battery 50. The battery ECU 52 outputs

data relating to the state of the battery 50 to the hybrid

electronic control unit 70 via communication according to the

20   requirements. The battery ECU 52 calculates a state of charge

(SOC) of the battery 50, based on the accumulated

charge-discharge current measured by the current sensor, for

control of the battery 50.

The hybrid electronic control unit 70 is constructed as

25   a microprocessor including a CPU 72, a ROM 74 that stores

processing programs, a RAM 76 that temporarily stores data, and

a non-illustrated input-output port, and a non-illustrated
communication port. The hybrid electronic control unit 70
receives various inputs via the input port: an ignition signal
from an ignition switch 80, a gearshift position SP from a
5 gearshift position sensor 82 that detects the current position
of a gearshift lever 81, an accelerator opening Acc from an
accelerator pedal position sensor 84 that measures a step-on
amount of an accelerator pedal 83, a brake pedal position BP
from a brake pedal position sensor 86 that measures a step-on
10 amount of a brake pedal 85, and a vehicle speed V from a vehicle
speed sensor 88. The hybrid electronic control unit 70
communicates with the engine ECU 24, the motor ECU 40, and the
battery ECU 52 via the communication port to transmit diverse
control signals and data to and from the engine ECU 24, the motor
15 ECU 40, and the battery ECU 52, as mentioned previously.
said motor.

The hybrid vehicle 20 of the embodiment thus constructed
calculates a torque demand to be output to the ring gear shaft
32a functioning as the drive shaft, based on observed values
20 of a vehicle speed V and an accelerator opening Acc, which
corresponds to a driver's step-on amount of an accelerator pedal
83. The engine 22 and the motors MG1 and MG2 are subjected to
operation control to output a required level of power
corresponding to the calculated torque demand to the ring gear
25 shaft 32a. The operation control of the engine 22 and the motors
MG1 and MG2 selectively effectuates one of a torque conversion

drive mode, a charge-discharge drive mode, and a motor drive mode. The torque conversion drive mode controls the operations of the engine 22 to output a quantity of power equivalent to the required level of power, while driving and controlling the

5   motors MG1 and MG2 to cause all the power output from the engine 22 to be subjected to torque conversion by means of the power distribution integration mechanism 30 and the motors MG1 and MG2 and output to the ring gear shaft 32a. The charge-discharge drive mode controls the operations of the engine 22 to output

10   a quantity of power equivalent to the sum of the required level of power and a quantity of electric power consumed by charging the battery 50 or supplied by discharging the battery 50, while driving and controlling the motors MG1 and MG2 to cause all or part of the power output from the engine 22 equivalent to the

15   required level of power to be subjected to torque conversion by means of the power distribution integration mechanism 30 and the motors MG1 and MG2 and output to the ring gear shaft 32a, simultaneously with charge or discharge of the battery 50. The motor drive mode stops the operations of the engine 22 and drives

20   and controls the motor MG2 to output a quantity of power equivalent to the required level of power to the ring gear shaft 32a.

The description now regards the operations of the hybrid vehicle 20 of the embodiment having the configuration discussed

25   above. Fig. 2 is a flowchart showing a drive control routine executed by the hybrid electronic control unit 70. This routine

is carried out repeatedly at preset time intervals (for example, at every several msec).

In the drive control routine, the CPU 72 of the hybrid electronic control unit 70 first inputs various data required for control, that is, the accelerator opening Acc from the accelerator pedal position sensor 84, the brake pedal position BP from the brake pedal position sensor 86, the vehicle speed V from the vehicle speed sensor 88, rotation speeds Nm1 and Nm2 of the motors MG1 and MG2, and an input limit Win, and an output limit Wout, and a charge-discharge power demand Pb* of the battery 50 (step S100). The rotation speeds Nm1 and Nm2 of the motors MG1 and MG2 are computed from the rotational positions of the respective rotors in the motors MG1 and MG2 detected by the rotational position detection sensors 43 and 44 and are received from the motor ECU 40 by communication. The input limit Win and the output limit Wout of the battery 50 are set based on the temperature Tb of the battery 50 measured by the temperature sensor 51 and the observed current state of charge (SOC) of the battery 50 and are received from the battery ECU 52 by communication. The charge-discharge power demand Pb* of the battery 50 is set based on the current state of charge (SOC) of the battery 50 and is received from the battery ECU 52 by communication.

After the data input, the CPU 72 sets a torque demand Tr* to be output to the ring gear shaft 32a or the drive shaft linked to the drive wheels 63a and 63b as the torque required for the

vehicle and a drive power demand Pv* required to drive the hybrid vehicle 20, based on the input accelerator opening Acc, the input brake pedal position BP, and the input vehicle speed V (step S110). A concrete procedure of setting the torque demand

5 Tr* in this embodiment stores in advance variations in torque demand Tr* against the accelerator opening Acc, the brake pedal position BP, and the vehicle speed V as a torque demand setting map in the ROM 74 and reads the torque demand Tr* corresponding to the given accelerator opening Acc, the given brake pedal

10 position BP, and the given vehicle speed V from the map. One example of the torque demand setting map is shown in Fig. 3. The drive power demand Pv* is set to the greater between a value '0' and the product of the torque demand Tr*, which depends on the accelerator opening Acc, and a rotation speed Nr of the ring

15 gear shaft 32a. The rotation speed Nr of the ring gear shaft 32a is obtained by multiplying the vehicle speed V by a conversion coefficient k or by dividing the rotation speed Nm2 of the motor MG2 by a gear ratio Gr of the reduction gear 35.

The drive power demand Pv* is then compared with the value

20 '0' (step S120). When the drive power demand Pv* is equal to 0, the torque demand Tr* is either 0 or a negative value. This means no requirement of power output from the engine 22 and thus allows the engine 22 to be at a stop as described later. When the drive power demand Pv* is greater than 0 at step S120, power

25 output from the engine 22 is required. An engine power demand Pe* to be output from the engine 22 is accordingly calculated

as the sum of the product of the torque demand Tr* and the

rotation speed Nr of the ring gear shaft 32a, the

charge-discharge power demand Pb* of the battery 50, and a

potential loss (step S130). An engine speed demand Nereq is

5   set as a rotation speed of the engine 22 at an efficient drive

point that ensures efficient output of the engine power demand

Pe* from the engine 22 (step S140). A concrete procedure of

setting the engine speed demand Nereq in this embodiment stores

in advance a variation in engine speed demand Nereq against the

10   engine power demand Pe* as an engine speed demand setting map

in the ROM 74 and reads the engine speed demand Nereq

corresponding to the given engine power demand Pe* from the map.

One example of the engine speed demand setting map is shown in

Fig. 4. The efficient drive point of the engine 22 (rotation

15   speed Ne × torque Te) ensuring the efficient output of the engine

power demand Pe* may be expressed by an operation line in a

torque-rotation speed map as shown in Fig. 5. The combination

of the rotation speed and the torque at an intersection between

a curve of constant engine power demand Pe* (shown by the broken

20   line) and the operation line gives the efficient drive point

of the engine 22 ensuring the efficient output of the engine

power demand Pe*.

The CPU 72 subsequently sets a lower engine speed limit

Nemin as a rotation speed of the engine 22 at a specific drive

25   point that ensures efficient output of a required power from

the engine 22 for a constant-speed drive of the hybrid vehicle

20 at the vehicle speed V (step S150). A concrete procedure

of setting the lower engine speed limit Nemin in this embodiment

stores in advance a variation in lower engine speed limit Nemin

against the vehicle speed V as a lower engine speed limit setting

5   map in the ROM 74 and reads the lower engine speed limit Nemin

corresponding to the given vehicle speed V from the map. One

example of the lower engine speed limit setting map is shown

in Fig. 6. A reference vehicle speed Vref shown in Fig. 6 is

set as a criterion for determining requirement of intermittent

10   operations of the engine 22.

        The CPU 72 then sets the greater between the engine speed

demand Nereq and the lower engine speed limit Nemin to a target

rotation speed Ne* of the engine 22 (step S160), and divides

the engine power demand Pe* by the target rotation speed Ne*

15   to calculate a target torque Te* of the engine 22 (step S170).

Setting the greater between the engine speed demand Nereq and

the lower engine speed limit Nemin to the target rotation speed

Ne* of the engine 22 aims to assure a quicker response to an

abrupt increase in engine power demand Pe*. In one example,

20   the driver may step on the accelerator pedal 83 in a decelerating

state with some decrease (but not to the zero level) in drive

power demand Pv*, while the hybrid vehicle 20 runs at a

relatively high speed. Under such conditions, the engine speed

demand Nereq is lower than the lower engine speed limit Nemin.

25   In general, the engine power increase by only a torque rise is

attained within a shorter time period than the engine power

increase by only a rotation speed rise. This is ascribed to the less time required for increasing the intake air flow and the amount of fuel injection than the time required for increasing the rotation speed of the rotational system of the

5 engine 22. Namely the engine 22 driven at the lower engine speed limit Nemin, which is higher than the engine speed demand Nereq, has a quicker response to a demand for output power increase from the engine 22.

The CPU 72 subsequently calculates a target rotation

10 speed Nm1* of the motor MG1 from the target rotation speed Ne* of the engine 22, the rotation speed Nr (= Nm2/Gr) of the ring gear shaft 32a, and a gear ratio ρ of the power distribution integration mechanism 30 according to Equation (1) given below, while calculating a torque command Tm1* of the motor MG1 from

15 the calculated target rotation speed Nm1* and the current rotation speed Nm1 of the motor MG1 according to Equation (2) given below (step S210):

Nm1* = Ne*·(1+ρ)/ρ − Nm2/(Gr·ρ)   (1)

20 Tm1* = Previous Tm1* + k1(Nm1*−Nm1) + k2∫(Nm1*−Nm1)dt   (2)

Equation (1) is a dynamic relational expression of the rotation elements included in the power distribution integration mechanism 30. Fig. 7 is an alignment chart showing

25 torque-rotation speed dynamics of the respective rotation elements included in the power distribution integration

mechanism 30. The left axis 'S' represents the rotation speed

of the sun gear 31 that is equivalent to the rotation speed Nm1

of the motor MG1. The middle axis 'C' represents the rotation

speed of the carrier 34 that is equivalent to the rotation speed

5 Ne of the engine 22. The right axis 'R' represents the rotation

speed Nr of the ring gear 32 that is obtained by multiplying

the rotation speed Nm2 of the motor MG2 by the gear ratio Gr

of the reduction gear 35. Equation (1) is readily introduced

from this alignment chart of Fig. 7. Two thick arrows on the

10 axis 'R' respectively show a torque that is transmitted to the

ring gear shaft 32a when the torque Te* is output from the engine

22 in steady operation at a specific drive point of the target

rotation speed Ne* and the target torque Te*, and a torque that

is applied to the ring gear shaft 32a via the reduction gear

15 35 when a torque Tm2* is output from the motor MG2. Equation

(2) is a relational expression of feedback control to drive and

rotate the motor MG1 at the target rotation speed Nm1*. In

Equation (2) given above, 'k1' in the second term and 'k2' in

the third term on the right side respectively denote a gain of

20 the proportional and a gain of the integral term.

     After calculation of the target rotation speed Nm1* and

the torque command Tm1* of the motor MG1, the CPU 72 calculates

a lower torque restriction Tmin and an upper torque restriction

Tmax as minimum and maximum torques output from the motor MG2

25 according to Equations (3) and (4) given below (step S220):

$$Tmin = (Win - Tm1^* \cdot Nm1) / Nm2 \qquad (3)$$

$$Tmax = (Wout - Tm1^* \cdot Nm1) / Nm2 \qquad (4)$$

The lower torque restriction Tmin and the upper torque

5 restriction Tmax are respectively given by dividing a

difference between the input limit Win of the battery 50 and

power consumption (power generation) of the motor MG1, which

is the product of the torque command Tm1* and the input current

rotation speed Nm1 of the motor MG1, and a difference between

10 the output limit Wout of the battery 50 and the power consumption

(power generation) of the motor MG1 by the input current

rotation speed Nm2 of the motor MG2. The CPU 72 then calculates

a tentative motor torque Tm2tmp to be output from the motor MG2

from the torque demand Tr*, the torque command Tm1* of the motor

15 MG1, the gear ratio ρ of the power distribution integration

mechanism 30, and the gear ratio Gr of the reduction gear 35

according to Equation (5) given below (step S230):

$$Tm2tmp = (Tr^* + Tm1^* / \rho) / Gr \qquad (5)$$

20

The CPU 72 limits the tentative motor torque Tm2tmp to the range

between the calculated lower torque restriction Tmin and upper

torque restriction Tmax to set a torque command Tm2* of the motor

MG2 (step S240). Setting the torque command Tm2* of the motor

25 MG2 in this manner restricts the torque demand Tr* to be output

to the ring gear shaft 32a or the drive shaft within the range

between the input limit Win and the output limit Wout of the
battery 50. Equation (5) is readily introduced from the
alignment chart of Fig. 7.

The CPU 72 sends the target rotation speed Ne* and the
target torque Te* of the engine 22 to the engine ECU 24, while
sending the torque commands Tm1* and Tm2* of the motors MG1 and
MG2 to the motor ECU 40 (step S250), before exiting from the
drive control routine. The engine ECU 24 receives the target
rotation speed Ne* and the target torque Te* and executes fuel
injection control and ignition control of the engine 22 to drive
the engine 22 at the specified drive point of the target rotation
speed Ne* and the target torque Te*. The motor ECU 40 receives
the torque commands Tm1* and Tm2* and executes switching control
of the switching elements included in the respective inverters
41 and 42 to drive the motor MG1 with the torque command Tm1*
and the motor MG2 with the torque command Tm2*.

When it is determined at step S120 that the drive power
demand Pv* is equal to 0 at step S120, the CPU 72 specifies no
requirement of power output from the engine 22 and gives a
command of cutting the fuel supply to the engine 22 (step S180).
According to a concrete procedure, the hybrid electronic
control unit 70 sends a fuel cut control signal to the engine
ECU 24 via the communication port. The CPU 72 subsequently sets
the lower engine speed limit Nemin, which is read corresponding
to the vehicle speed V from the lower engine speed limit setting
map as described above, to the target rotation speed Ne* of the

engine 22 (step S190), and sets the torque command Te* of the engine 22 equal to 0 (step S200). The CPU 72 then executes the processing of steps S210 to S240 to set the torque commands Tm1* and Tm2* of the motors MG1 and MG2 and sends the settings to

5   the engine ECU 24 and to the motor ECU 40 (step S250), before exiting from the drive control routine. When the vehicle speed V is lower than the reference vehicle speed Vref, the lower engine speed limit Nemin is set equal to 0. The engine 22 is accordingly stopped without rotations.

10   The driver may step on the accelerator pedal 83 in an accelerator-off state, while the hybrid vehicle 20 runs at a relatively high speed. In the accelerator-off state, the drive power demand Pv* is equal to 0. The engine 22 accordingly has a fuel cut and is rotated at the lower engine speed limit Nemin.

15 The driver's depression of the accelerator pedal 83 under such conditions cancels the fuel cut and immediately resumes the intake air flow and the fuel injection to output the torque from the engine 22. The engine 22 is rotated at the lower engine speed limit Nemin, which causes the engine 22 to efficiently

20 output a required power for a constant-speed drive of the hybrid vehicle 20 at the current vehicle speed V. Simple adjustment of the intake air flow and the amount of fuel injection immediately enables the engine 22 to efficiently output the required power for a constant-speed drive of the hybrid vehicle

25 20. The drive point of the engine 22 changes along the operation line (see Fig. 5), which represents continuation of efficient

engine drive points, from the specific drive point that enables

the engine 22 to efficiently output the required power for a

constant-speed drive. This control ensures a quicker response

of the engine 22 to output the required power, compared with

5   the conventional control of driving the engine 22 at a low

rotation speed or stopping the engine 22. In the configuration

of the hybrid vehicle 20 of the embodiment, as clearly shown

by the setting of the tentative motor torque Tm2tmp at step S230,

the output torque of the motor MG2 driven with the electric power

10   supply from the battery 50 compensates for a delayed response

of the engine 22. The quick output of the required power from

the engine 22 reduces the discharge electric power of the

battery 50 and desirably decreases the loading of the battery

50. This arrangement thus effectively prevents premature

15   deterioration of the battery 50, which is accelerated by

repeated charges and discharges of relatively high electric

powers.

     As described above, the hybrid vehicle 20 of the

embodiment drives the engine 22 at the rotation speed of not

20   lower than the lower engine speed limit Nemin corresponding to

the vehicle speed V, so as to enhance the response of the engine

22 to a change in output power demand. The control of the

embodiment desirably reduces an insufficiency of the required

driving power due to a delayed response of the engine 22, thus

25   lowering the required discharge level of the battery 50 and

reducing the load of the battery 50. The lowered charge and

discharge levels desirably prevent premature deterioration of the battery 50, which is accelerated by repeated charges and discharges at relatively high electric power levels. The quicker response of the engine 22 also ensures a prompt shift of the drive point of the engine 22 to the efficient engine drive points along the operation line. In the case of no requirement of power output from the engine 22 with the drive power demand Pv* equal to 0, the control procedure of the embodiment stops the fuel injection to the engine 22 and thus desirably improves the fuel consumption.

The hybrid vehicle 20 of the embodiment sets the lower engine speed limit Nemin to the specific rotation speed of the engine 22 at the specific drive point that ensures efficient output of the required power for a constant-speed drive of the hybrid vehicle 20 on the flat road surface at the vehicle speed V. This rotation speed level is, however, not essential, and the lower engine speed limit Nemin may be set to be slightly lower or slightly higher than the specific rotation speed at the specific drive point.

The hybrid vehicle 20 of the embodiment sets the greater between the value '0' and the product of the torque demand Tr*, which depends on the accelerator opening Acc, and the rotation speed Nr of the ring gear shaft 32a, to the drive power demand Pv*. One possible modification may set the drive power demand Pv* to the product of the torque demand Tr*, which depends on the accelerator opening Acc, and the rotation speed Nr of the

ring gear shaft 32a, to the drive power demand Pv*. Another

possible modification may set the drive power demand Pv* to the

torque demand Tr*, which depends on the brake pedal position

BP. In such modified structures, the fuel cut control depends

5   on whether the drive power demand Pv* is a positive level or

not.

      The hybrid vehicle 20 of the embodiment drives the engine

22 in response to the drive power demand Pv* of higher than 0,

while cutting off the fuel supply to the engine 22 in response

10   to the drive power demand Pv* equal to 0. One possible

modification may drive the engine 22 in response to the drive

power demand Pv* of higher than a preset threshold value Pref

(greater than 0), while cutting off the fuel supply to the engine

22 in response to the drive power demand Pv* of lower than the

15   preset threshold value Pref.

      In the hybrid vehicle 20 of the embodiment, the power of

the motor MG2 is subjected to gear change by the reduction gear

35 and is output to the ring gear shaft 32a. In one possible

modification shown as a hybrid vehicle 120 of Fig. 8, the power

20   of the motor MG2 may be output to another axle (that is, an axle

linked with wheels 64a and 64b), which is different from an axle

connected with the ring gear shaft 32a (that is, an axle linked

with the wheels 63a and 63b).

      In the hybrid vehicle 20 of the embodiment, the power of

25   the engine 22 is output via the power distribution integration

mechanism 30 to the ring gear shaft 32a functioning as the drive

shaft linked with the drive wheels 63a and 63b. In another possible modification of Fig. 9, a hybrid vehicle 220 may have a pair-rotor motor 230, which has an inner rotor 232 connected with the crankshaft 26 of the engine 22 and an outer rotor 234

5   connected with the drive shaft for outputting the power to the drive wheels 63a, 63b and transmits part of the power output from the engine 22 to the drive shaft while converting the residual part of the power into electric power.

The embodiment discussed above is to be considered in all

10 aspects as illustrative and not restrictive. There may be many modifications, changes, and alterations without departing from the scope or spirit of the main characteristics of the present invention. The scope and spirit of the present invention are indicated by the appended claims, rather than by the foregoing

15 description.

Industrial Applicability

The technique of the invention is desirably applicable to manufacturing industries of hybrid vehicles and power output

20 apparatuses.